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# Mobiles Energy Consumption in LTE Uplink Networks

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***Abstract*— 3GPP has standardized different multicarrier access methods in the downlink and uplink for LTE. While Orthogonal Frequency Division Multiple Access (OFDMA) is chosen in the downlink, Single Carrier Frequency Division Multiple Access (SC-FDMA) is chosen in the uplink due to its low Peak-to-Average Power Ratio (PAPR) which plays a crucial role in the User Equipment's (UE) power consumption. This paper presents two set of analysis- first being the performance and comparison of Best-Effort Resource Block (RB) Scheduling algorithms based on the Resource Block usage ratio and their impact on the overall throughput. The second is to determine the Signal-to-Interference-plus-Noise Ratio (SINR) per RB per UE. As the SINR at any instant is directly proportional to the power of the UE/RB, under this assumption the UE/RB power can be reduced. Based on the minimum SINR/UE/RB that can be achieved, the power control is then introduced on each of the UE/RB to obtain the least possible power for transmitting the data while maintaining the throughput. A Channel Quality Indicator (CQI) table is used as a reference to obtain the new SINR for each UE/RB. The difference between the new and the old SINR is calculated which gives the amount by which the UE/RB power can be reduced without affecting the throughput. The results obtained show a reduction in the power consumption by upto 28%.**

***Index Terms*— Power control, LTE, SC-FDMA, RB allocation.**

## I. INTRODUCTION

3GPP's Long Term Evolution (LTE) since its inception has changed the phase of wireless communication specifically in mobile broadband technology with data throughput reaching new heights [1]. This achievement of high speeds for mobile devices has opened doors to many functionalities- high quality video calls, seamless streaming of online videos and the latest being the mobile television to name a few. But then it also means that the UE now handles more data transmissions and receptions, which translates to the level of the UE's battery consumption. The first solution to this problem was to use a technology that in itself required low power to operate and hence SCFDMA [11] was chosen as the multicarrier access scheme for LTE uplink networks. Few of the prominent techniques to reduce the power consumption of the UE are shortly briefed. A technique called Sleep mode [2] where the UE can alternate between a fixed period Sleeping window (SW) and a pre-fixed period but extendable Listening window (LW). While in SW the UE can power down some of its circuitry to save power. The UE does not wake up until it has completed its SW even when there are data to be received. The LW is used to scan the network for new or pending data intended for the UE. Discontinuous Reception (DRX) [2] [3] also works on the similar lines of Sleep mode but unlike Sleep mode it wakes up immediately when new or pending data is sent to it by the Base Station (BS). An interesting method is proposed [4] where the energy consumption can be decreased by allocating

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more RBs to a UE which also increases the throughput but it was achieved at the expense of increased power. Loop Power control techniques [5] is done in two ways: Open Loop Power Control (OPLC) method, where the UE decides the power level depending on the channel conditions at that instant and Closed Loop Power Control (CLPC) method where the UE decides the power level based on the channel conditions as well as the feedback from the BS. The studies so far have not considered the power consumption in an RB which inadvertently translates to the power consumed by the UE. In this paper, we have introduced a novel method to reduce power by utilizing the SINR information per RB of the communication channel. Each RB experiences a different SINR due to the random nature of the channel caused by fading, noise and obstacles that could be from a car to a high rise building or mountains. These SINRs are then compared with the SINR levels given in the CQI table [10]. The lower bound of the SINR level to which an SINR value falls is chosen as the new value, while the throughput remains unchanged clearly seen from the table. Difference between the new and the old SINR is obtained which is used as a metric by which the UE can reduce its power to transmit the data at the same throughput. All through the simulation the MCS conditions laid out for LTE uplink is considered i.e., the same MCS must be used on all the RBs that have been assigned to a UE. Scheduling of the RBs in this paper is achieved by using the Best Effort -RB schedulers. These set of schedulers were chosen as they give priorities to the UE/RB with good SINR conditions as a result of which data transmission failure is minimum.
The system is a 7 cell network and only one sector is considered for the analysis. A 5 MHz bandwidth was used which allots 25 RBs [12] for the system per half the Transmit Time Interval (TTI). A TTI is 1 micro seconds.
The paper is structured as follows: Section II explains the Best effort RB scheduling algorithms, Section III gives the description of the SINR based power control algorithm, Section IV describes the system model, Section V analyses the performances of the Best effort RB scheduling algorithms, Section VI shows the results obtained and section VII concludes and discusses the future works.

## II. Best Effort -RB Scheduling Algorithms

Best Effort -RB scheduling algorithms are schedulers that assign the RBs based on the UE-RB pair that has the highest value of the utility metric/function. They aim to maximize the utilization of the radio resources and may or may not consider the fairness [6] (fair distribution of the resources amongst the users).

### *A. Heuristic Localized Gradient Algorithm (HLGA).*

In [7] the authors have presented a scheduler called Heuristic Localized Gradient Algorithm which finds the UE-RB pair that has the maximum value. Once all the deserving UEs have been served, then it checks for RBs that are not adjacent to each other but have been allocated to the same UE. In such a case it allocates the RBs between them to the same UE. Finally if any RBs are still remaining, it allocates them to UE-RB pairs that satisfy the contiguity constraint. This management of free RBs makes it a zero-RB-wastage scheduler.

TABLE I. HLGA

| | **RB 1** | **RB 2** | **RB3** | **RB 4** | **RB 5** | **RB 6** |
|---|---|---|---|---|---|---|
| **UE 1** | **0.26** | **1.65** | **0.10** | **1.60** | **0.85** | **0.88** |
| **UE 2** | **0.82** | **0.50** | **0.30** | **0.90** | **0.63** | **0.87** |
| **UE 3** | **0.41** | **0.39** | **0.47** | **0.62** | **0.89** | **0.59** |

Table I shows the assignment of RB’s to UE’s by HLGA. The colour assignments are as follows: Red depicts UE 1, green depicts UE 2 and blue depicts UE 3.The values given in the boxes are the value of a metric/utility function as chosen by the developer.
RB 2 and RB 4 are assigned to UE 1 in the first step as all of them have a higher value. But when it scans RB 5 it finds that it has a higher value to UE 3 and so it assigns RB 5 to UE 3. Next it goes to RB 6 and finds that it can’t assign it to UE 1 because it would violate the contiguity constraint so instead it assigns to UE 2. Now it checks for any RBs that will satisfy the contiguity constraint. And in this case since RB 3 comes in between RB 2 and RB 4 which are assigned to UE 1, it is also assigned to UE 1 to satisfy the contiguity constraint. Also as RB 1 is not assigned to any UE it is allocated to UE 1 as it satisfies the contiguity constraint.

### *B. Frequency Domain Packet Scheduling (FDPS).*

The authors of [8] have proposed four heuristic algorithms.

i. FDPS-carrier-by-carrier
ii. FDPS-largest-metric-value-RB-first
iii. FDPS-riding peaks
iv. FDPS-RB-grouping

*FDPS-carrier-by-carrier:* The FDPS-carrier-by-carrier is a sequential RB allocating algorithm. It allocates the RB's starting by taking the first RB and finding which user gives the maximum UE-RB value. Once a UE has been assigned a RB, it can no longer be assigned RBs unless it satisfies the contiguity constraint. Then it moves on to the next RB and correspondingly finds the UE with the highest UE-RB value.

Table II shows the assignment of the RBs. Here RB 1 is scanned first and as UE 2 has the highest value it assigns it to UE 2. Next RB 2 is scanned and since UE 1 has a higher value it assigns it to UE1. Then it goes to RB 3 and finds that UE 3 has a high value and hence it is given to UE 3. When it reaches RB 4, it can't assign it to UE 1 as it violates the contiguity constraint, as it moves on to RB 5, UE 3 has the highest value and it satisfies the contiguity constraint, hence it is assigned to UE 3 again. RB 6 again belongs to UE 1 but it can't be assigned to it again for the same reasons. As this scheme sequentially assigns the RBs to the UEs, it leads to an unlikely event of a UE's highest metric being allotted to it.

*FDPS-largest-metric-value-RB-first:* The FDPS-largest-metric-value-RB-first is similar to HLGA as it allocates the users with the highest UE-RB metric first and assigns the RBs between adjacent RBs as well. But it does not deal with the extra remaining unused RBs. The other downside is the assignment of all the RBs that fall between two high UE-RB value to a particular UE could lead to some users not assigned any RBs.

Table III clearly shows that RB 1 is left unused and is not allotted to any user. This problem is more prominent when the number of UEs is less the number of RBs allocated to a system and does not occur if the number of UEs is more than the RBs.

TABLE II. FDPS-CARRIER-BY-CARRIER

| | **RB 1** | **RB 2** | **RB3** | **RB 4** | **RB 5** | **RB 6** |
|---|---|---|---|---|---|---|
| **UE 1** | **0.26** | **1.65** | **0.10** | **1.60** | **0.85** | **0.88** |
| **UE 2** | **0.82** | **0.50** | **0.30** | **0.90** | **0.63** | **0.87** |
| **UE 3** | **0.41** | **0.39** | **0.47** | **0.62** | **0.89** | **0.59** |

TABLE III. FDPS-LARGEST-METRIC-VALUE-RB-FIRST

| | **RB 1** | **RB 2** | **RB3** | **RB 4** | **RB 5** | **RB 6** |
|---|---|---|---|---|---|---|
| **UE 1** | **0.26** | **1.65** | **0.10** | **1.60** | **0.85** | **0.88** |
| **UE 2** | **0.82** | **0.50** | **0.30** | **0.90** | **0.63** | **0.87** |
| **UE 3** | **0.41** | **0.39** | **0.47** | **0.62** | **0.89** | **0.59** |

TABLE IV. FDPS-RIDING PEAKS

| | **RB 1** | **RB 2** | **RB3** | **RB 4** | **RB 5** | **RB 6** |
|---|---|---|---|---|---|---|
| **UE 1** | **0.26** | **1.65** | **0.10** | **1.60** | **0.85** | **0.88** |
| **UE 2** | **0.82** | **0.50** | **0.30** | **0.90** | **0.63** | **0.87** |
| **UE 3** | **0.41** | **0.39** | **0.47** | **0.62** | **0.89** | **0.59** |

TABLE V. FDPS-RB GROUPING

| | **RB 1** | **RB 2** | **RB3** | **RB 4** | **RB 5** | **RB 6** |
|---|---|---|---|---|---|---|
| **UE 1** | **0.26** | **1.65** | **0.10** | **1.60** | **0.85** | **0.88** |
| **UE 2** | **0.82** | **0.50** | **0.30** | **0.90** | **0.63** | **0.87** |
| **UE 3** | **0.41** | **0.39** | **0.47** | **0.62** | **0.89** | **0.59** |

*FDPS-riding peaks:* The third algorithm specified in their paper, the FDPS-riding-peaks assigns each user the RB with whom it has a maximum UE-RB value. This approach seems good in terms of user fairness for slow varying channels where there are slight changes in the channel conditions between adjacent RBs. In such channel conditions the maximum or peaks of each UE are allocated their corresponding RBs. Then the RBs around the peak RBs will also be allocated to the same UE. This assures that the highest metric of each UE is

used. But in cases where the channel conditions across the RBs changes rapidly it turns out to be wasting a lot of RBs. This also results in allocating a UE at most only one RB which makes a UE transmit at maximum power as the power is always divided amongst the RBs allocated to a UE. As shown in table IV only RB 2, RB 3 and RB 5 are used and the remaining RBs are never used.

*FDPS-RB-grouping:* The last algorithm, the FPDS-RB-grouping overcomes the shortcoming of FDPS-riding-peaks by grouping the RBs into 'n' groups, each with 'm' RBs. The "peak riding" is then applied over these RB groups. Thus the rapid channel variations can be overcome.

Here the RBs are grouped into 3 groups with 2 RBs each (table V). The UEs are allocated the RB groups depending on who has the highest value in the RB group. The different shadings denote the RB groups. FPDS-RB-grouping gives a better performance over FDPS-riding-peaks only when there are lesser number of UEs.

### *C. First Maximum Expansion (FME).*

FME [9] first finds the UE-RB that has the highest metric value. Then it checks for the next highest UE-RB on its right and left sides. If it still belongs to the same UE, it assigns to the RB to the same UE. It expands to the right if the right UE-RB value is greater than the left UE-RB value and vice versa if the left is greater than the right. This continues until the next highest UE-RB value belongs to another UE. And again it repeats the process of checking the UE-RB values on its right and left side. This algorithm also incorporates the management of the remaining free RBs making it a zero-RB-wastage scheduler.

As shown in table VI, UE 1-RB 2 has the highest metric. It then checks on its left and right side. As neither side belongs to it, on to its left UE 2 is assigned RB 1. RB 3 is assigned to UE 3. It then checks the value on the right which belongs to UE 1 but it cannot be assigned to UE 1 as it violates the contiguity constraint. So it checks for the next highest UE-RB and again it belongs to UE2 which obviously violates the contiguity constraint. Hence the remaining RBs are allocated to UE 3 as it satisfies the contiguity constraint.

### *D. Recursive Maximum Expansion (RME).*

RME [9] is also similar to FME but the difference is it will always begin a new search for the highest UE-RB every time a user has been allocated an RB and none of the adjacent RBs belong to it. This process is repeated until all the RBs have been used or all the users have been served. If there are unused RBs, they are allocated only if the contiguity constraint is satisfied. It also incorporates the management of the free RBs.

Table VII shows the allotment of RB's. RB 2 having the highest value is assigned to UE 1. Then it checks on the right and left to find any RBs that are of high value and belong to it. But since none of the RBs that are of high value belong to it, it starts a new search. UE 1 can now no longer be assigned RBs until all the UE have been assigned an RB. The next highest value is RB 4 but since UE 1 has already been served it cannot be assigned to it. So instead it assigns it to UE 2 as RB 1 has the highest value and it hasn't been served. Then again it checks for the highest values on either side but since none belong to it starts the scan all over again to find the highest value available. Due to this repeatedly scanning process it is called recursive. Lastly, any RBs that are not used are assigned to UEs which satisfies the contiguity constraint.

TABLE VI. FIRST MAXIMUM EXPANSION

| | **RB 1** | **RB 2** | **RB3** | **RB 4** | **RB 5** | **RB 6** |
|---|---|---|---|---|---|---|
| **UE 1** | **0.26** | **1.65** | **0.10** | **1.60** | **0.85** | **0.88** |
| **UE 2** | **0.82** | **0.50** | **0.30** | **0.90** | **0.63** | **0.87** |
| **UE 3** | **0.41** | **0.39** | **0.47** | **0.62** | **0.89** | **0.59** |

## III. SINR BASED POWER CONTROL

The SINR based power control method uses the knowledge of the $SINR_{eff}$, effective Signal-to- Interference plus Noise ratio. $SINR_{eff}$ is the SINR of each resource element in a RB. The reason for using this metric is for the very fact that each resource element experiences different levels of SINR. This helps us to have a better estimate of the channel conditions. Using a CQI table described in [10] where the SINR is divided in 15 different levels, the SINR obtained is then compared with the SINR given in the CQI table. Depending on where the current SINR falls, the lower boundary of the SINR is assigned as the new SINR. The difference between the new SINR and the old SINR is calculated and used a metric to reduce the power of the UE. As the SINR is the ratio of the signal power and the noise plus interference, it is assumed that at a particular instant, the SINR is directly proportional to the signal power or the transmitter power. So, reducing the SINR

translates to reducing the UE power as well.

TABLE VII. RECURSIVE MAXIMUM EXPANSION

| | **RB 1** | **RB 2** | **RB3** | **RB 4** | **RB 5** | **RB 6** |
|---|---|---|---|---|---|---|
| **UE 1** | **0.26** | **1.65** | **0.10** | **1.60** | **0.85** | **0.88** |
| **UE 2** | **0.82** | **0.50** | **0.30** | **0.90** | **0.63** | **0.87** |
| **UE 3** | **0.41** | **0.39** | **0.47** | **0.62** | **0.89** | **0.59** |

IV. *UE'S TRANSMITTING POWER:*

The transmitting power of the UE is calculated by the following formulae

$$P_{min}=\min( P_{new}, P_{ue})\ \text{dBm} \quad (1)$$

where,

$P_{min}$= minimum transmitting power, dBm

$P_{new}$= power obtained from the CQI table, dBm

$P_{ue}$ = power of UE without applying the power control method, dBm

$P_{ue}$ is given by,

$$P_{ue} = P_{max} – 10\log_{10}(M) \quad (2)$$

Where,

$P_{max}$= 21 dBm

M= number of RBs allocated to a user

$P_{new}$ is formulated as follows,

$$P_{new}= P_{ue} - (SINR_{obt} - SINR_{red}) \quad (3)$$

where,

$SINR_{obt}$= SINR generated from the channel

$SINR_{red}$= SINR obtained from the CQI table

The difference obtained is considered unitless and hence is just a metric.

$$SINR_{obt} =\sum SINR_{ue}/ N \quad (4)$$

where,

N= 25, number of RBs

$SINR_{ue}$ is the SINR of a user over an RB and C is the Shannon capacity given by

$$C=1/N \sum \log2(1+ SINR_{eff}) \quad (5)$$

As mentioned earlier $SINR_{eff}$ is the effective SINR per resource element per user and is mathematically formulated as

$$SINR_{eff} = P*G_{UE}*G_{BS}(\theta)*G_{Ch}/ n+I \quad (6)$$

where,

P : transmitting power of a UE over one resource element

$G_{UE}$ : antenna gain of the UE

$G_{BS}(\theta)$ : antenna gain of the BS

$\theta$ : angle between the UE and the BS

n : thermal noise in the subcarrier

I : inter-cell interference per resource element

$G_{Ch}$ : total channel gain= $P_L * S_{SHD}$

$P_L$ : pathloss between a UE and the BS

$S_{SHD}$ : log-normal shadowing

Table VIII shows an example of how the power reduction is carried. The steps can be viewed in the order of the left column towards the right column.

Assume that the users UE 1, UE 2 and UE 3 were transmitting at $P_{max}$. The SINR of each UE is obtained and is subtracted from the SINR values obtained from the CQI table. The difference is then stored as a difference metric and has no unit associated with it. The difference metric is then subtracted from each UE's transmitting power to obtain the new power which is lower than the previous transmitting powers of the UEs.

***Algorithm***

1. *Let **S** be the SINR matrix of the UEs that have been allocated RBs.*
2. *Let $\boldsymbol{P_{ue}}$ be the matrix of the initial UEs powers and $\boldsymbol{S_{CQIL}}$, $\boldsymbol{S_{CQIU}}$ be the lower and upper bounds of the CQI SINR levels respectively.*
3. *Let **S_new** be the matrix of the new SINRs obtained from the CQI table.*
4. *If $S_{CQIL} \leq S(i,j) \leq S_{CQIU}$ i=1: number of UEs; j=1: number of RBs then, $S\_new(i,j) = S_{CQIL}$*
5. ***For** i=1: number of UEs*
6. ***For** j=1: number of RBs*
7. *Diff(i,j) = S(i,j) - S_new(i,j)*
8. *$P_{new}(i,j) = P_{ue}(i,j)$ - Diff(i,j)*
9. *Find $\boldsymbol{P_{min}(i,j)} = \min(P_{ue}(i,j), P_{min}(i,j))$*
10. ***End***
11. ***End***

TABLE VIII: POWER REDUCTION USING THE SINR TO CQI MAPPING

| | Current SINR (dB) | New SINR from the CQI table (dB) | Difference Metric | Power of UE (dBm), $P_{max}$ | Reduced power (dBm) |
|---|---|---|---|---|---|
| **UE1** | 13.3099 | 11.5 | 1.8099 | 20.9691 | 19.1592 |
| **UE2** | 8.13943 | 7 | 1.1394 | 20.9691 | 19.8297 |
| **UE3** | 18.7021 | 17 | 1.7021 | 20.9691 | 19.2670 |

## V. SYSTEM MODEL

A 7 cell hexagonal network shown in fig. 1 was considered for the simulations. The system parameters are given in table IX.

The UEs, denoted by the red cross, are equally spaced at about 48 meters from each other. A total of 388 possible UEs position per sector is generated. The base stations, denoted by the green triangle, of the outer cells, referred to as the interfering cells, are at a distance of 1732 meters from the central base station.

The UEs are transmitting at the $P_{max}$ i.e., 21 dBm. The inter cell interference in obtained by the following formulae

$$I_{(k,i)} = P_{max} * G_{UE} * G_{BS}(\theta) * G_{Ch} / P_L * S_{SHD} \quad (7)$$

where,

$I_{(k,i)}$ : ICI of the $i^{th}$ user in the $k^{th}$ cell, $k$=1-6
$P_{max}$ : transmitting power of a UE
$G_{UE}$ : antenna gain of the UE
$G_{BS}(\theta)$ : antenna gain of the BS
$\Theta$ : angle between the UE and the BS
n : thermal noise in the subcarrier
$P_L$ : pathloss between a UE and the BS
$S_{SHD}$ : log-normal shadowing

Four different scenarios were analyzed for the ICI.

*Scenario 1:* A user from each interfering (outer) cell was chosen. These users were placed exactly at the same positions in each of the interfering cells.

*Scenario 2:* Just as scenario 1, one user from each interfering cells was chosen. But unlike scenario 1, these users were randomly placed in each of the outer interfering cells.

*Scenario 3:* Here the users were placed as far as possible and away from the radiation coverage of the central base station so that they generated less interference on the central cell.

*Scenario 4:* Lastly, the users were placed as close and in line of the radiation coverage on the central base station thereby generating the maximum interference.

Scenarios 3 and 4 are the best and worst case of inter-cell interference of our system and serve as the boundary for checking the validity of the ICIs of scenarios 1 and 2. Fig. 2 shows the cumulative distribution function (CDF) of the inter-cell interference for the various scenarios. From the figure it can be clearly seen that the ICI of scenario 1 and 2 fall between the ICI of scenario 3 and 4 which is what we desire. For the simulation the ICI value of the randomly placed users i.e., scenario 2, is chosen given its practical reality.

TABLE IX: SYSTEM PARAMETERS

| Parameter | Value |
|---|---|
| Network layout | 7 cells, 3 sectors/cell |
| Propagation scenario | Macro 3 ( ISD 1.7 Km) |
| Thermal noise, n | -160 dBm/Hz |
| Base station antenna gain, $G_{BS}$ | 17 dBi |
| UE antenna gain, $G_{UE}$ | 7 dBi |
| System Bandwidth | 5 MHz |
| Number of Resource Blocks, N | 25 |
| Maximum UE transmitting power | 21 dBm |
| Traffic | Full buffer |
| Shadowing | Log-normal shadowing with $\sigma$=5 dB |
| Path loss model | Okumura-Hata Model<br>$\alpha$= 137 dB, $\gamma$ = 34 dB |
| UE height | 1.5 meters |
| BS height | 35 meters |
| Number of users per simulation | 10,20,40,60 and 100 |

The pathloss of the users was generated using Okumura-Hata's model for a large city and is depicted in fig. 3. The pathloss is given as,

$$P_L = A + B*\log_{10}(d) \qquad (8)$$

Where,

$A = 69.55 + 26.16*\log_{10}(fc) - 13.82*\log10(h_{bs})) - a_{hm}$;

$B = 44.9 - 6.55*\log_{10}(h_{bs})$;

$a_{hm} = 3.2*(\log10(11.75*h_{ue}))^2 - 4.97$, antenna height correction factor

d = distance between the users and the base station

$h_{bs}$ = height of BS, $h_{ue}$= height of UE

The effective SINR was obtained by using (6) and its CDF is shown in fig. 4. It can be inferred that the system has a SINR range of about 40 dB.

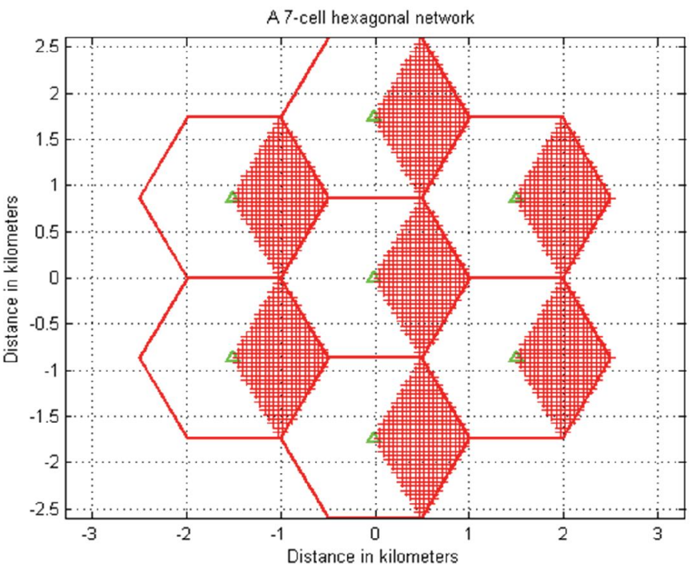


Figure 1. 7 cell network

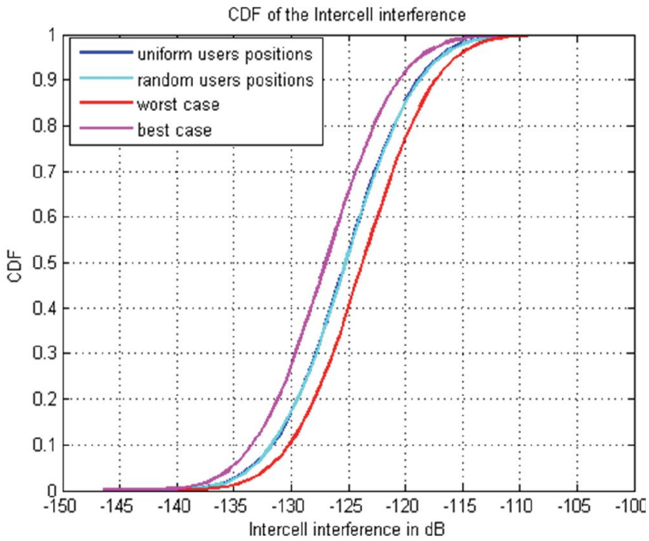


Figure 2. CDF of Inter-cell interference

The capacity of the system was calculated using Shanon's capacity which is given by,

$$C=1/N \sum \log 2(1+ SINR_{eff}) \quad (9)$$

Using the obtained capacity C, the spectral efficiency was calculated using the CQI table shown in table X. Fig. 5 shows the spectral efficiency and the Shannon's capacity bound for the derived $SINR_{eff}$.

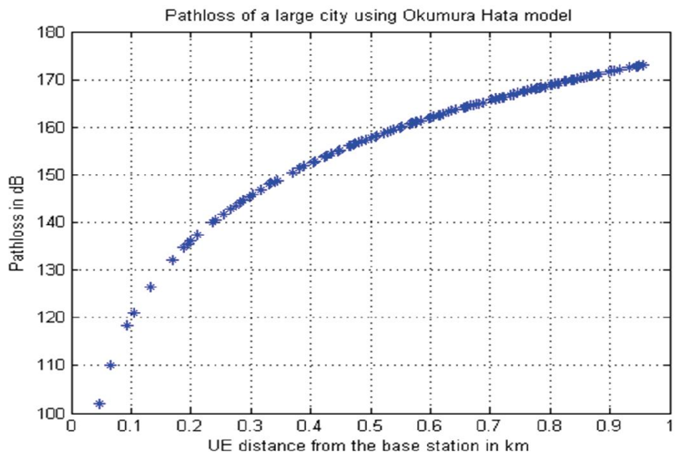


Figure 3. Pathloss generated using Okumura-Hata's model

VI. PEFORMANCE ANALYSIS

*A. RB Usage Ratio.*

The RB usage ratio is the amount of RB that has been used per transmit time interval (TTI) to the total available RB of the system in percentage.
It is given as follows.

$$RB_{usage}= RB_{allc}/N \text{ x } 100 \% \quad (10)$$

Where,

$RB_{usage}$ = RB usage ration in percentage
$RB_{allc}$ = RBs used by the allocation algorithm per TTI
N = 25, total number of RBs for the system per TTI

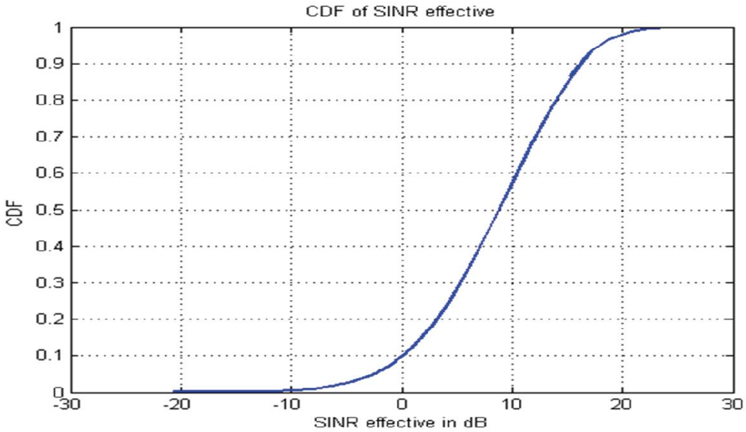


Figure 4. CDF of $SINR_{eff}$

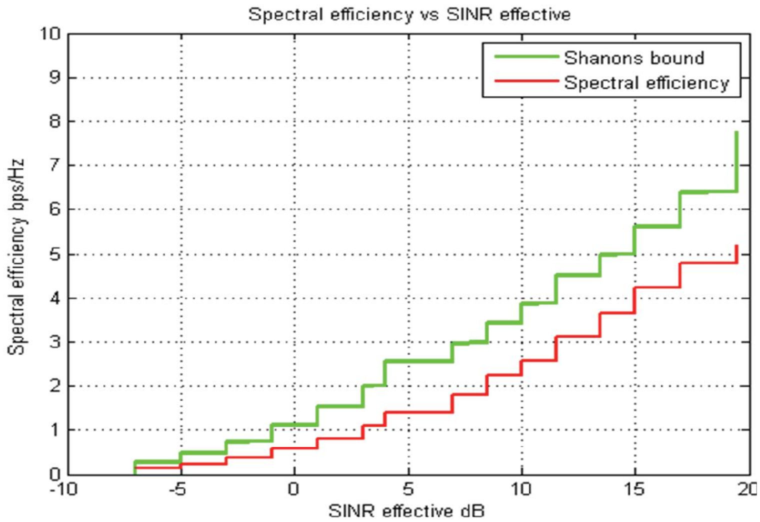


Figure 5. Spectral efficiency with Shannon's bound.

From fig. 6 it can be clearly seen that HLGA, FME and RME always uses all the RBs as all of them incorporate the free RBs management scheme. On the other hand FDPS-largest-metric-value-RB-first shows a steady growth in the RB usage as the number of UEs increases and achieves full usage of the RBs once the number of UEs is more than the number of RBs.

The curve of FDPS Riding Peaks follows an exponential growth as the number of UEs increases whereas the FPDS-RB-grouping has a better performance over FPDS Riding Peaks when the number of UE is 10 which was anticipated and greater then 10 UEs it has a very poor graph.

FDPS-carrier-by-carrier has the worst performance as the UEs that have assigned RBs cannot be reassigned new RB unless they satisfy the contiguity constraint. This is limiting the allocation of several RBs to a UE and hence aggregates in the poor usage of RBs.

*B. Overall Throughput Of The System*

The overall throughput generated by each algorithm is analyzed and shown in fig. 7. The throughput of the system is obtained by using MCS data rates specified in the CQI table, table X [10]. FDPS-carrier-by-carrier and FPDS-RB-grouping are below the 50 Mbps mark in all the cases of different set of UEs and this can be understood and justified from the very fact that they also had the lowest RB usage ratio. Note that the throughput of FPDS-RB-grouping is better then FDPS Riding Peaks for 10 UEs but beyond that it is less then FDPS Riding Peaks which is also related to the RB usage ratio. HLGA, FME and RME show a steady

increase in the throughput as the number of UEs increases. FDPS-largest-metric-value-RB-first shows the best increase in throughput as it always chooses the highest SINR valued RB for a UE. It can be seen that it even out performs FME which actually has a 100% RB usage ratio in all cases of set of UEs. This is for the fact that FME does not always choose the highest SINR valued RB unlike FDPS-largest-metric-value-RB-first.

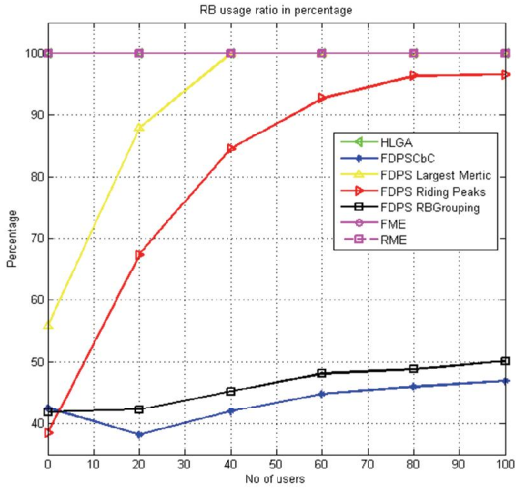


Figure 6. RB usage ratio

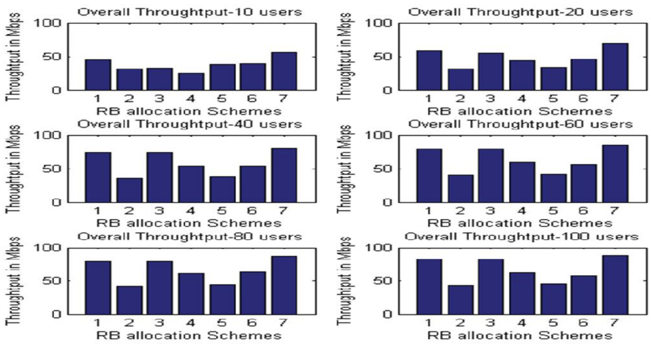


Figure 7. Overall throughput of the system.

## VII. RESULTS

From the performance analysis of the scheduling algorithms, it can be clearly deduced that the throughput is directly proportional to the RB usage ratio. A special case has been observed where the throughput of FME is less than FDPS-largest-metric-value-RB-first despite FMEs 100% RB usage ratio compared to 90% RB usage ratio of FDPS-largest-metric-value-RB-first. The reason being FDPS-largest-metric-value-RB-first always chooses only the highest SINR valued RB whereas FME does not necessarily do so. The proposed SINR based power control method was applied to each of the algorithms. Though not shown, the throughput of the system is not affected and remains the same even after the power control was applied.

The performances of each algorithm are summarized in the table XI.

The aim of this method was to reduce the transmitting power of the UEs as much as possible and in a way avoid transmitting at the maximum power i,e., 21 dBm. Fig.8 and fig.9 show the before and after results. The effects of power control are clearly visible for FDPS Riding Peaks. It shows that the transmitting power was always at 21 dBm regardless of the number of UEs as at most only one RB is allocated to a UE. By applying the power control algorithm it can be seen that the power per RB is around 19 dBm. It has been reduced by 2

dBm (46 mWatts). Similar trend in the reduction of the power per RB can be seen for the other algorithms as well. Thus there is a significant amount of change in the power per RB by applying the power control.

TABLE X. CQI TABLE [10].

| SINR Range (dB) | CQI | Modulation | Code rate | Bits per Resource element (Kbps) |
|---|---|---|---|---|
| -7< SINR ≤ -5 | 1 | QPSK | 0.0761 | 0.1523 |
| -5< SINR ≤ -3 | 2 | QPSK | 0.1172 | 0.2344 |
| -3< SINR ≤-1 | 3 | QPSK | 0.1884 | 0.3770 |
| -1< SINR ≤1 | 4 | QPSK | 0.3008 | 0.6016 |
| 1< SINR ≤3 | 5 | QPSK | 0.4384 | 0.8770 |
| 3< SINR ≤5 | 6 | QPSK | 0.5879 | 1.1758 |
| 5< SINR ≤7 | 7 | 16QAM | 0.3691 | 1.4766 |
| 7< SINR ≤8.5 | 8 | 16QAM | 0.4785 | 1.9141 |
| 8.5< SINR ≤10 | 9 | 16QAM | 0.6015 | 2.4063 |
| 10< SINR ≤11.5 | 10 | 64QAM | 0.4550 | 2.7305 |
| 11.5< SINR ≤13.5 | 11 | 64QAM | 0.5537 | 3.3223 |
| 13.5 < SINR ≤15 | 12 | 64QAM | 0.6504 | 3.9023 |
| 15< SINR ≤17 | 13 | 64QAM | 0.7539 | 4.5234 |
| 17< SINR ≤19.5 | 14 | 64QAM | 0.8525 | 5.1152 |
| SINR ≥19.5 | 15 | 64QAM | 0.9258 | 5.5547 |

TABLE XI: PERFORMANCE TABLE

| | **RB usage (%)** | **Throughput (Mbps)** | **Power reduction per UE (%)** |
|---|---|---|---|
| **HLGA** | 100 | 69.7293 | 24.2587 |
| **FDPS-C-by-C** | 43 | 37.3265 | 28.0282 |
| **FDPS-LMF** | 90 | 67.0087 | 24.2908 |
| **FDPS-RP** | 79 | 50.8961 | 20.9174 |
| **FDPS-RBG** | 46 | 40.3780 | 27.2601 |
| **FME** | 100 | 53.0164 | 25.6464 |
| **RME** | 100 | 77.6781 | 24.1837 |

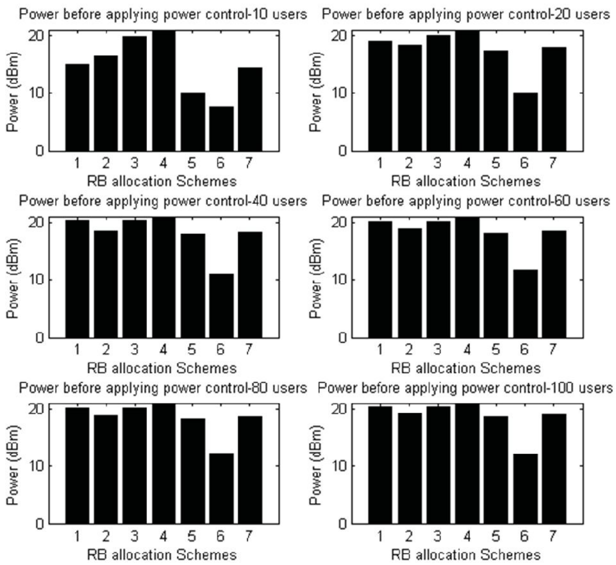


Figure 8. Power per RB before power control

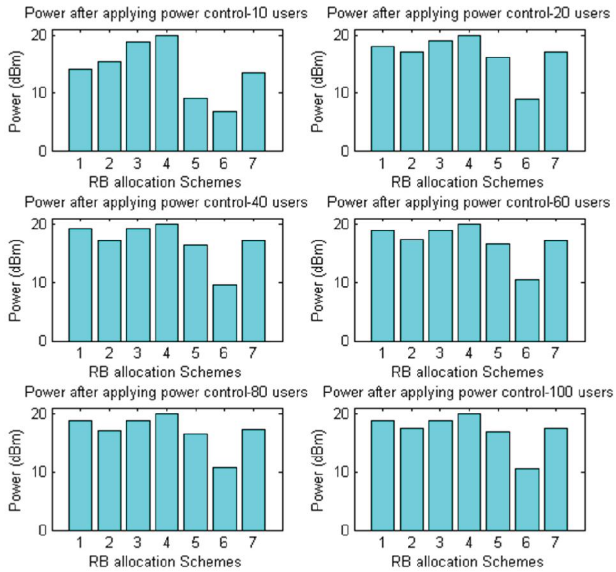


Figure 9. Power per RB after power control

## VIII. CONCLUSIONS AND FUTURE WORKS

The proposed power control method with its simplicity has proven to be an effective method to reduce the transmission power of the UEs in LTE uplink networks. The power of the UEs which were found to be as high as 125 mWatts in the case of FDPS-riding-peaks and as low as 70 mWatts in the case of FME without the power control was drastically reduced to 98.5 mWatts and to 48.19 mWatts respectively after the power control was applied. The findings show that the power per UE/RB can be reduced by upto 28% and proves that SINR based power control will help ease the battery consumption of the UE without decreasing the throughput.

The throughput of the system was very good because of the use of the Best Effort Schedulers. HLGA, FDPS-largest-metric-value-RB-first and Recursive Maximum Expansion have shown better performances in both the RB usage ratio and the throughput. Throughput of the system could reach upto 77 Mbps (RME) and RB usage of upto 100% in cases of HLGE, FME and RME.

This work can be extended to networks that incorporate relays which should produce a further reduction of the UEs power. Also a model of the UE power performance with the SINR based power control can be designed to test the performance of the algorithm in real time.

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